NASA TECH BRIEF

Optimum Structural Design Based on Reliability and Proof-Load Testing

Thermomechanical properties (such as fracture strength, elasticity modulus and deformation capacity) of materials used in the structure of vehicles exhibit considerable statistical variations. Furthermore, severe environments and loading conditions involve a number of uncertainties as to temperatures generated by aerodynamic friction, dynamic pressures, axial accelerations, and vibration loads. This indicates that both the strength of a structure and loads acting on the structure should be treated as random variables and that the concept of structural reliability should be incorporated into the analysis of the structure and its optimum design. The major structural components of a vehicle are usually tested individually, or otherwise under simulated environmental and loading conditions before the vehicle is deployed. Since such simulated tests or proof-load tests are indispensable parts of the engineering task within a test program, it is extremely important that the effect of such tests be taken into account in the estimation of structural reliability and in the structural design. This study presents quantitative results of weight saving and increased reliability by taking into consideration the proof-load test.

From the viewpoint of reliability analysis, the performance of the proof-load test can improve not only the reliability value itself but also the statistical confidence in such a reliability estimate. This is because the proof-load test eliminates structures with strength less than the proof load. Therefore, it is obvious that the reliability of a structure chosen from this subset is higher than that of a structure chosen from the original population. Further, the proof-load test truncates the distribution function of strength at the proof load, thereby alleviating the analytical difficulty of verifying the validity of a fitted distribution function at the lower tail portion where data are usually nonexistent. Obviously, the difficulty still remains in the selection of a distribution function for the load. However, the statistical confidence in the reliability estimation now depends mainly on the accuracy of the load prediction. Rational methods to deal with the statistical confidence of the load distribution are discussed in detail in which the Bayesian approach is suggested.

An approach is developed for optimizing a structural design (for either minimum weight or minimum expected cost) by introducing the proof load as an additional design parameter, and the practical adtantages of the use of proof loads in terms of weight saving are demonstrated by numerical examples. The importance of the proposed method in structural design is emphasized because it represents a truly rational approach in the area clouded by uncertainties. Moreover, it establishes a definite design procedure applicable to most aerospace structures.

Although the present study places its emphasis on the problem of optimization of aerospace structures, the principle involved can be applied to optimization problems in other engineering disciplines (such as design of civil engineering structures, naval structures, ground vehicles, material-handling equipment, and electronic systems). In particular, the optimization can be highly significant for electronic systems consisting of thousands of components when the cost of each component is so small in comparison with the total cost of the system that a relatively high level of proof load can be applied.

(continued overleaf)

Note:

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